

The Whakahura Programme

EXTREME EVENTS AND THE EMERGENCE
OF CLIMATE CHANGE: A SYNTHESIS

*Noho tahanga a Papatūānuku kia
whakakorowai i a ia.*

*Our earth mother is laying bare, she is
exposed, we need to cloak her in order to
mitigate the impacts of climate change.*

A whakatauaāki gifted by Keita Ngata (Ngāti Porou)

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SYNTHESIS WRITER: Jo Hazel — Relate Strategic.

DESIGNER: Hailey Benton — [The Creatives](#).

1. Introduction

The changing frequency and severity of extreme weather events is of significant importance to Aotearoa New Zealand. Examples include widespread floods impacting rural and urban areas, cyclones and storm surges threatening coastal communities, and fire hazards endangering forestry ... the list goes on. These events affect financial institutions, economic development, and human wellbeing and cultural practices. Understanding extreme weather phenomena and their impacts is critical for making effective and efficient adaptation decisions across all sectors. Whakahura means to uncover or discover in Te Reo Māori.

During the past five years, the Whakahura Programme has built a substantial body of work and a rich understanding of the extent to which anthropogenic emissions of greenhouse gasses (GHGs) influence extreme weather. In particular it has examined how extreme weather events (EWEs) are changing and will continue to change and, crucially, team members have evaluated the effects of these hazards on economic assets, natural systems, wellbeing and te ao Māori.

As a science-based programme, Whakahura has examined the data and methodologies used in climate research, and has advanced the state of the art as a result.

Whakahura was characterised by a focus on extreme weather, an intention to support decision-making, and a desire to fill existing knowledge gaps. Ultimately, it has succeeded in demonstrating the urgency of adapting to these contemporary and growing phenomena in the current time.

A FOCUS ON EXTREME WEATHER

Whakahura is the first research program dedicated to investigating extreme weather related to climate change in Aotearoa New Zealand.

Why focus on extreme weather? Because focusing on average changes can obscure high and low extremes. Rather than studying some of the slower evolving aspects of climate change (such as sea level rise), which do not yet cause too much impact in this country, the team have increased our understanding of expected changes in frequency and severity of extreme weather. These events already cause a great deal of harm, and so the research provides support to those leading adaptation efforts.

Extreme weather includes unexpected, unusual, severe, or unseasonal weather, which is at the extremes of the distribution and range observed historically.

There is a common misunderstanding that extreme weather cannot be attributed to climate change, however, event attribution science is a field that has developed a great deal over the last 20 years, and Whakahura has demonstrated clear links between climate change and some events.

“Climate change is more than just sea level rise.”¹

AID FOR DECISION-MAKING

While the programme has focussed on higher level decision-makers such as central government organisations, the insights generated are also relevant to others (directly or indirectly), including local government, businesses, hapū/iwi, Māori, community organisations, families and individuals.

Outputs from the programme are available to aid extreme weather-related decision-making and adaptation planning across the country. In particular, outputs have proven useful for entities such as the New Zealand Treasury, which has benefitted from Whakahura insights in their role as lead economic and financial advisor to the Government, enabling them to more knowledgeably factor in dynamic risks created by climate change. Whakahura research has also informed the Reserve Bank of New Zealand’s ‘stress testing’ activities.

Additionally, recognising that there has been a longstanding failure to draw on Māori knowledge in the field of national disaster risk reduction (both theoretical and applied), Whakahura researchers have provided evidence of the effectiveness of hapū/iwi-led adaptation practices, and produced advice for government authorities on how to partner fruitfully.

FILLING IDENTIFIED KNOWLEDGE GAPS

Prior to Whakahura, there was little dedicated domestic research into how extreme events might be expected to change in severity or frequency, and very little investigation of their current or future impact on the economy and society; Whakahura research has revealed which types of hazards are changing the fastest and which locations are most exposed.

Beyond Aotearoa New Zealand, Whakahura researchers were the first in the world to take on the task of generating an estimate of the current costs of climate change from extreme events globally², and this generated a great deal of public media interest, as well as researcher discussions about how extreme weather costs can most accurately be attributed to anthropogenic influence.

Because of their foundational nature, the methods and databases developed through the Whakahura Programme provide a robust, fundamental body of evidence for future researchers to draw on as this area of inquiry continues to develop and provide decision-relevant insights.

¹ Luke Harrington
² Article: The global costs of extreme weather that are attributable to climate change, 2023.



DEMONSTRATING THE RELEVANCE OF 'NOW'

“Whakahura is about, mostly, the climate change problem we currently have, not about the climate change problem we will have in some distant future.”³

Many people still believe that climate change is a future challenge, although this is beginning to change. Research drawing on physical and social sciences to better link attribution with cost estimates and human experience has demonstrated without a doubt that climate change is already causing increased economic, infrastructural, wellbeing and cultural damage. Whakahura has focused on impacts that might be expected within the next one to four decades, as this is the most policy-relevant timeframe.

3 Ilan Noy

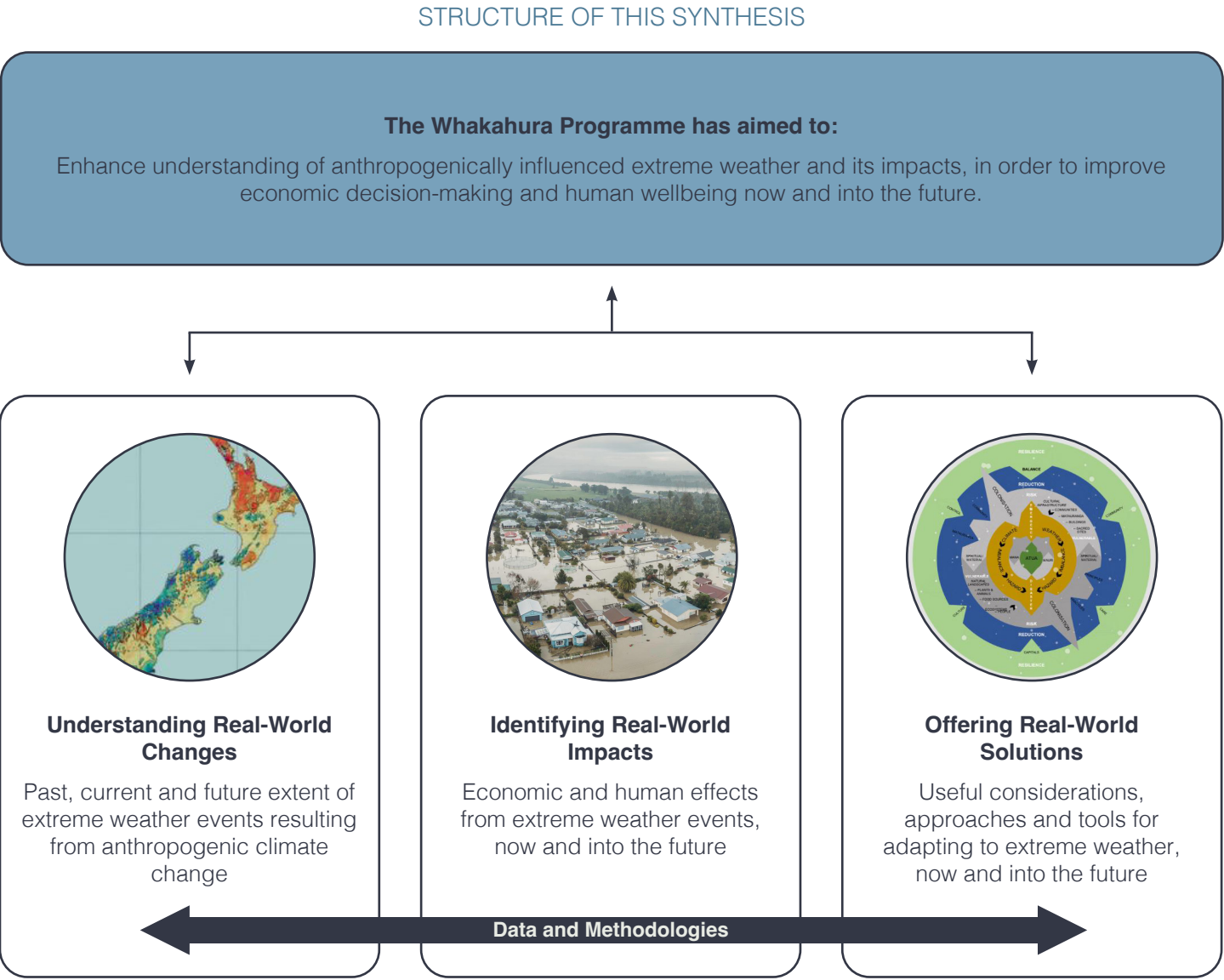


Fig 1: The Whakahura Program has Created New Knowledge in Three Specific Areas

The document⁴ highlights three areas of Whakahura research output: understanding real-world changes, identifying real-world impacts, and offering real-world solutions. It also briefly explores the research-policy interface and suggests fruitful areas for ongoing research into extreme weather.

Although this synthesis does not aim to present the full body of knowledge generated by the research team during the programme’s five-year lifespan, it does offer an overview and small snippets of the work so that readers might be inspired to explore the catalogue of research papers via links provided in Appendix 2.

4 This work has drawn from the Whakahura Proposal and Annual Reports, interviews with lead researchers, Whakahura research papers and related literature.

2. Whakahura Programme Structure

The programme comprised six streams that were each designed to address specific research questions, and involved multidisciplinary collaboration at times.

“Understanding how climate signals have emerged above natural variability in the recent past is the problem of detection and attribution. Understanding how climate change signals emerge above natural variability in the future is climate change emergence.”

WHAKAHURA FUNDING PROPOSAL, 2019

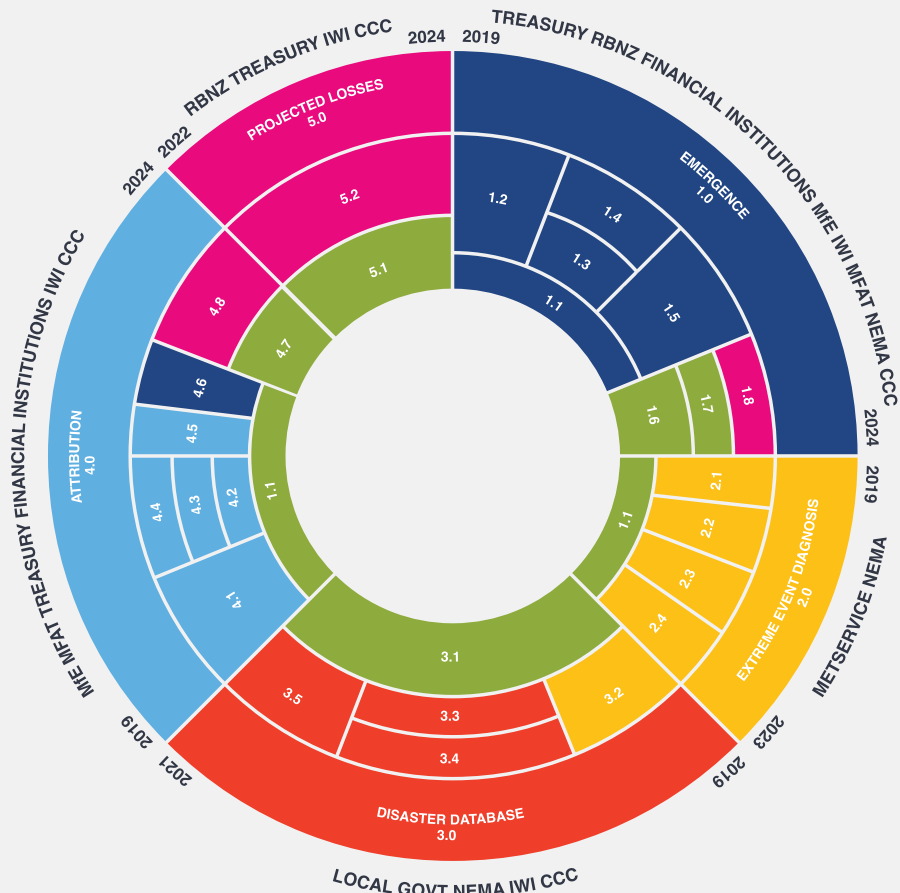


Fig 2: Whakahura Research Programme Incorporated Multiple Streams

Emergence [Research Aim 1]

Building on the exploration and quantification of climate change emergence over the previous decade, involving world-leading financial and infrastructure-related modelling and incorporating indigenous asset management expertise, in order to understand the emergence of climate change.

Extreme Event Diagnosis [Research Aim 2]

Drawing from experts in meteorology, atmospheric physics and mātauranga Māori, and building on existing relationships and previous work to improve diagnosis and simulation of past extreme weather events in Aotearoa New Zealand.

Disaster Database [Research Aim 3]

Bringing together world leaders in disaster economics, applied climate change economics using satellite imagery, civil engineering and disaster management, atmospheric physics and mātauranga Māori, in order to construct a Retroactive National Loss Database (2005-2017). Unfortunately, this Aim was not achieved as the pertinent data could not be obtained.

Attribution [Research Aim 4]

Bringing together physical climate scientists and economists at the cutting edge of methodological developments in attribution and the application of disaster techniques to diagnose the human role in past and current extreme weather and its impacts.

Projected Losses [Research Aim 5]

Drawing on the world-leading research produced in other Research Aims to demonstrate at the global scale the extent to which losses from extreme weather events can be attributed to climate change.

Vision Mātauranga (VM)⁵ [incorporated across all Research Aims]

Providing additional capability-building benefit to the wider team regarding kaupapa-Māori informed approaches.

5 Vision Mātauranga is a government science policy put in place in 2005 with the purpose of unlocking the science and innovation potential of Māori knowledge, resources and people for the benefit of all New Zealanders.

COLLABORATION

The wisdom of applying multidisciplinary collaboration to complex challenges is well-understood, and this was the approach taken within the Whakahura Programme from the outset. Physical scientists, economists, and researchers bringing a te ao Māori lens made up the multidisciplinary team. As Programme Director Dave Frame explains:

“We were certainly very keen to build something interdisciplinary that had links to real decision makers. So Belinda Storey’s focus on insurance markets, Ilan Noy’s focus on economics, and Shaun Awatere’s work with Māori groups and expertise in land economics - those are all practical, grounded skills that decision-makers will actually pay attention to.”⁶

While the core team was based in Aotearoa New Zealand, a number of international partners were also involved formally. Additionally, other researchers from across the world expressed interest in published Whakahura articles, collaborating informally at times to further evolve methodologies and share data.

Physical Scientists and Economists

A key differentiator of the programme was its integration of financial and economic analysis alongside climate science. As one researcher noted, cross-domain collaboration enabled them to gain new knowledge about other approaches: *“We’re coming at things from very different angles, but we’re coming to similar sorts of conclusions.”⁷*

And yet it would also be true to say that unanimous agreement has not always been reached. Physical scientists and economists often have different ideas about which models are appropriate to use in different settings, different ideas of how to treat uncertainties, and perhaps most importantly, when evidence was sufficiently reliable to be placed in front of decisionmakers. Whakahura intentionally took a pluralist approach to these issues, so as to trust researchers to follow the norms of their fields, on the grounds that there are strong benefits to a diversity of views, even if this has some costs in terms of strict coherence.

Vision Mātauranga

As several team members acknowledged, the full potential of collaboration between the VM team, physical scientists and economists, was not realised. This was in large part due to Covid preventing face-to-face meetings between researchers and communities at local marae, as had been planned. Overall, there has not been the level of research co-development originally intended.

Nevertheless, the non-Māori researchers were exposed to Māori community needs, aspirations and knowledge, which did enable some level of capability building in terms of learning about alternative worldviews. As the VM research leader noted, *“Raising the awareness of Māori issues for the climate modellers was a worthy outcome.”⁸*

6 Dave Frame
7 Dáithí Stone
8 Shaun Awatere

“We had a program which was kind of designed to join up the physics, the economics and Māori aspirations, and that interaction didn’t quite happen as much as we might’ve hoped, even if we have learned a lot from each other. But I think looking at the work that’s happened on all three of those sides, I think it’s been impressive in a disciplinary sense.”⁹

CAPABILITY DEVELOPMENT

Whakahura engaged a talented cohort of students who made a significant contribution to the programme’s research. Several of those students have been involved in important work, including Rebecca Newman, whose work with Ilan Noy, ‘The Global Costs of Extreme Weather Attributable to Climate Change’, was published in Nature Communications and has been presented to the Reserve Bank of New Zealand and the World Bank, as well as being cited by major media outlets. Cameron McErlich’s paper, ‘Positive Correlation Between Wet-Day Frequency and Intensity Linked to Universal Precipitation Drivers’, was published by Nature Geoscience.

“There’s such a significant need for this research and there’s so many unanswered questions that it means when a PhD or Master’s student comes in, they’re working on genuinely ground-breaking stuff.”¹⁰

9 Dáithí Stone
10 Belinda Storey

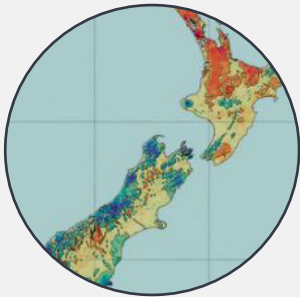
3. Understanding Real-World Changes

KEY POINTS

- 1. Anthropogenic climate change is not a future challenge; it is already creating significant impacts in the current time. In particular, it is increasing both the probability and intensity of extreme weather events.
- 2. Some hazards are increasing more quickly than others: heat, short intense rainfall events and fire risk are changing fastest in Aotearoa New Zealand.
- 3. Places currently vulnerable to particular hazard types will experience more of those hazards in the future.
- 4. Globally, climate data availability and quality differs by hazard type and location.
- 5. Climate science attribution methodology needs to be tailored; there is no superior one-size-fits-all approach. Methodological approaches also matter in terms of identifying impacts.

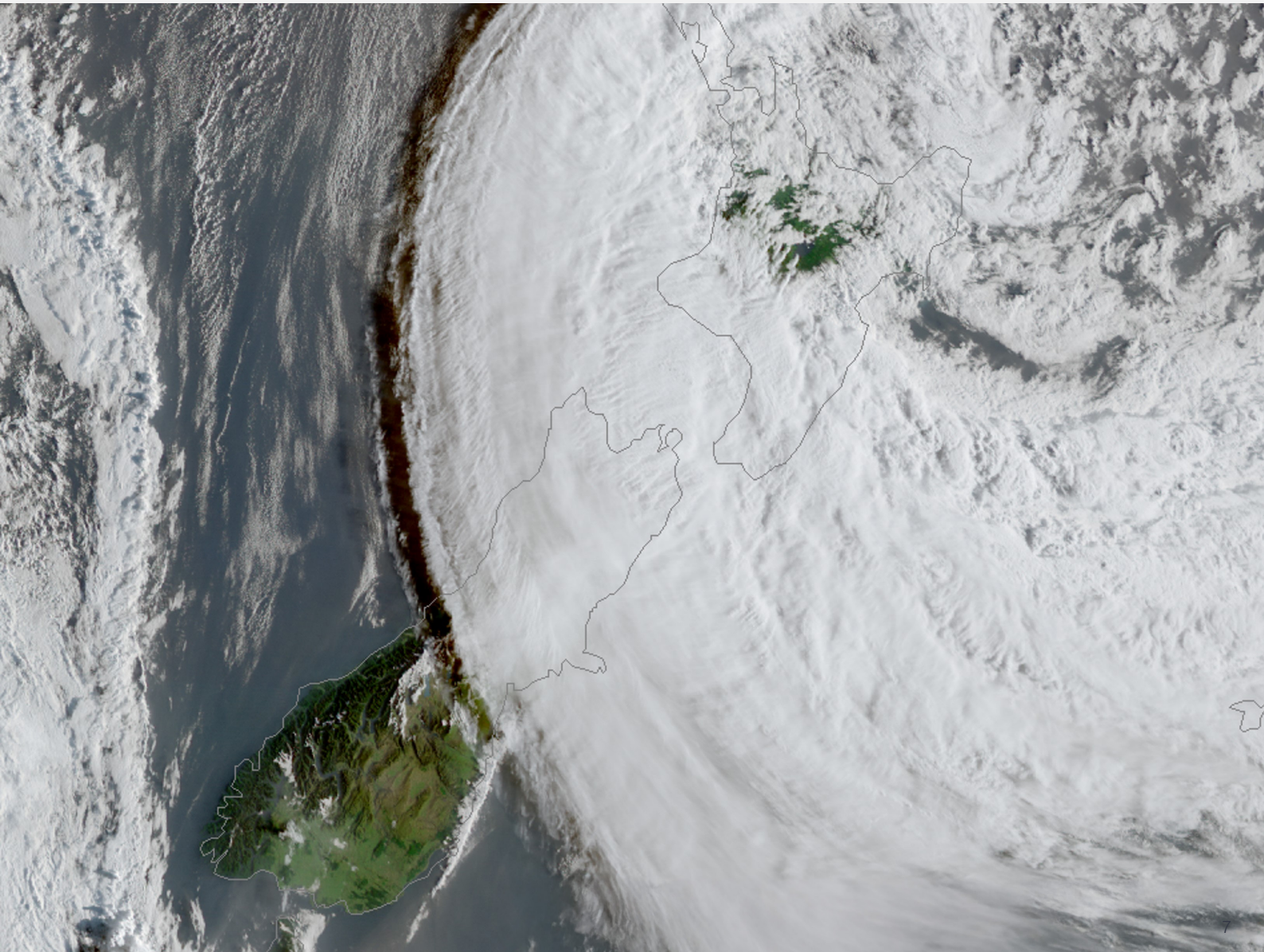
METHODOLOGY AND DATA

Extreme Event Attribution (EEA) science was first applied in the early 2000s and has continued to evolve since that time. In very simple terms, it quantifies changes in the likelihood or intensity of Extreme Weather Events (EWEs) resulting from anthropogenic climate change. However, its execution is a complex area, with uncertainties and methodological nuances that must be carefully navigated to produce findings that are accurate and verifiable. While Whakahura researchers sought to discover more about these hazards, they also examined the very methods used in the evolving field of climate science, and in doing so have advanced the state of the art.



Understanding Real-World Changes

Past, current and future extent of extreme weather events resulting from anthropogenic climate change



Through the use of attribution science, one can say that an event became more likely and/or more intense because of human-induced climate change, and equally, it is also sometimes possible to determine by how much.

Much of the research has tested different climate models, including various 'top down' and 'bottom up' approaches. The researchers have noted the importance of framing choices made regarding research questions, data sets, models and techniques. Methodology matters.

A specific methodological tactic has been to employ the weather@home climate model in some cases as an alternative to running a single, expensive and complex computer simulation. This tool is particularly relevant for Whakahura because it allows researchers to sample the tails of normal distributions¹¹ where evidence of extreme weather exists. While this approach may be a little contentious, as one researcher noted, *"We just took a very simple approach because you could get somewhere with it. Many people will say that in an ideal world, you would run a big flood model, and maybe so, but maybe you can get a ballpark estimate or maybe you can aggregate over events using the approaches we've taken."*¹²

Another area of exploration, which can inform research methodology, has been the linking of climate science and adaptation with mātauranga Māori, Aotearoa New Zealand's unique knowledge system. Being so closely concerned with the land, and based on long term observations, indigenous insights are particularly relevant to understanding the more extreme aspects of anthropogenic climate change.

11 A normal distribution is a symmetrical probability distribution curve often called a 'bell curve' when graphed. The centre represents the 'average' or most commonly occurring values, while values at the outer extremes of the curve, the 'tails', occur far less often. Extreme weather can be seen within these 'tails'.
12 Dave Frame

This broad, deep knowledge of the connections between people and the environment enables a more holistic conceptualisation of real-world change. Further, it speaks then to how extreme weather can be thought about and planned for, for example, through co-developing local adaptation strategies rather than national, one-size-fits-all approaches being externally imposed.

While the merits of different methodologies continues to be debated, in terms of the data available to climate scientists, information on anthropogenic extreme weather and its effects is skewed towards wealthier regions and certain hazard types,¹³ leaving glaring knowledge gaps. There are large areas of the globe without long-term operational weather stations producing the data needed for climate science, particularly for validating models. For example, there is significantly more information about mortality rates during heatwaves in Europe and North America even though high temperatures are a much larger risk for lower income countries such as those in sub-Saharan Africa.¹⁴ This lack of data constrains scientists' understanding of changes over time, as well as extreme weather impacts and adaptation options. Further, the inconsistencies within global measurements become more important as we move into a warmer future where a pre-industrial baseline is rendered somewhat irrelevant, and more contemporary comparators are needed.

13 Article: Challenges to Understanding Extreme Weather Changes in Lower Income Countries, 2020.
14 Article: Reconciling theory with the reality of African heatwaves, 2020.



EXTREME WEATHER HAZARDS

*"Things are happening simultaneously. The dry shoulder seasons are getting drier, but that's also being punctuated by increasingly more extreme wet days, particularly the very wet days are intensifying most rapidly."*¹⁵

Whakahura research has shown that extreme hazards have already begun increasing in both likelihood and intensity, that some events are changing faster than others, and that places already vulnerable to particular types of extreme weather should expect those hazards to increase over the coming years.

One study¹⁶ attempted to estimate the emergence of local climate change experienced across the global population, young and old, rich and poor. It showed that exposure to extreme weather has not been uniform, and this has implications for the ongoing impacts of climate change as well as adaptation decisions. In a local example, Northland, already susceptible to drought, will experience some of the biggest increases for this type of extreme, while the West Coast of the South Island will see increases in the most intense, short duration rainfall events.

Research on heat, precipitation and fire risk has revealed powerful insights into the future of Aotearoa New Zealand's climate, and each of these is discussed below.

1. Heat

Whakahura research shows that heat events are changing fastest of all the extreme weather event types.

Yet due to a long-standing perception that Aotearoa New Zealand does not experience extreme heat, this hazard type has not been a focus within domestic public policy, and there is a low level of relevant national data collected and collated. In response to this identified gap, the Whakahura Programme has produced much-needed local research on extreme heat.

One of the earlier heat-related papers¹⁷ evaluated different methods for quantifying extreme heat in this country with the aim of improving the knowledge base underpinning

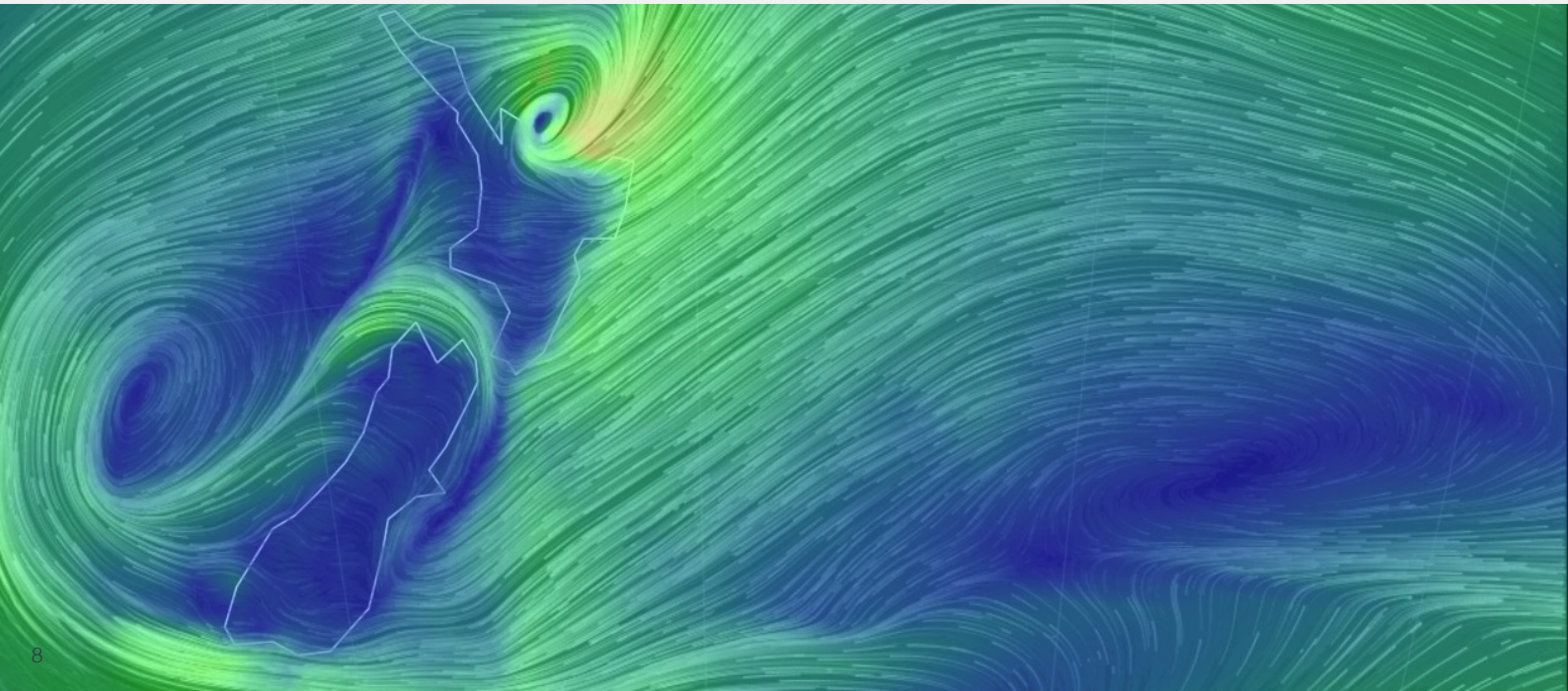
15 Luke Harrington
16 Article: Climate change emergence over people's lifetimes, 2023.
17 Article: Rethinking Extreme Heat in a Cool Climate: a New Zealand Case Study, 2021.

future heat-related risk assessments. One of the basic findings of this work is that the use of absolute temperature thresholds,¹⁸ as is commonly employed, is not an ideal approach. Instead, regionally relevant criteria should be used, and in this research, percentile thresholds were used to identify local heat anomalies. This alternative approach could be applied to assessing future heatwaves using more contemporary, local comparators.

Subsequent research¹⁹ that tested the use of heat ranges for different locations, examined the effects of night and day temperature changes, and also considered persistence of extreme heat. It shows that Aotearoa New Zealand's hottest days have seen increasing temperatures, as has happened in other parts of the world. At a finer level, in a 3 degrees warmer world there will be differences across regions in terms of daytime and overnight temperatures as well as the duration of successive days deemed 'hot'. Specific predictions are provided for different regions, with Napier and Gisborne considered at a very high risk of extreme heat (relative to local norms), while other areas have a significantly lower risk, including Invercargill and Wellington.

While Whakahura research has improved understanding of extreme heat in this country, given how quickly the likelihood and intensity of extreme heatwaves is increasing, these events will soon be entirely attributable to human-induced climate change. Given this likely future scenario, another study²⁰ looking at global heatwaves notes that in a hotter future, attribution science can usefully turn its attention to more targeted insights that provide information supportive of effective adaptation planning and action to lessen negative impacts. *"The tools that demonstrate climate change can affect extreme weather today, now need expanding to answer the questions of tomorrow."*²¹ For example, providing probabilistic, place-based insights linking extreme heat with energy system failure thresholds would assist with adaptive infrastructure planning.

18 It is generally accepted that a 'hot day' in Aotearoa New Zealand is any day that exceeds 25 degrees - it is based on the claim that this is the threshold for heat stress in cattle.
19 Article: Extreme heat in New Zealand: a synthesis, 2022.
20 Article: Integrating attribution with adaptation for unprecedented future heatwaves, 2022.
21 Article: Integrating attribution with adaptation for unprecedented future heatwaves, 2022, p5.



2. Precipitation

Whakahura research shows that in terms of extreme rainfall, the fastest change is being seen in intense, short duration events as the world gradually warms.

The Auckland Anniversary Weekend floods in early 2023 were an example of this type of event and show the negative impacts that can result. Cyclone Gabrielle hit a short time later, with significant damage being recorded across many regions, and 11 people losing their lives in Hawkes Bay and Te Tairāwhiti. Te Tairāwhiti had already experienced multiple localised extreme precipitation events during the preceding 18 months, and Gabrielle saw levels of rainfall akin to Cyclone Bola in 1988.

Research indicates that the intensity of short duration extreme rainfall events is increasing faster than are longer events, for example, hour-long events are expected to be around 18% more intense with each degree of average warming.²² Within Aotearoa New Zealand, Northland and the Southern Alps will likely experience the largest increase in this type of hazard.

Further research,²³ which employed large ensemble techniques, showed that in a future with three degrees of global warming, locations that experience little change in average rainfall are in fact likely to have wetter wet days, while their driest days will tend to produce less rainfall compared with today. Overall, there is expected to be a three-fold increase in the incidence of extreme dry years, and generally more volatile and uneven precipitation. To better understand what factors may be related to this type of

22 Article: Changing rainfall extremes with climate change in New Zealand; Guidance for Decision-makers, 2024.
23 Article: Robust changes to the wettest and driest days of the year are hidden within annual rainfall projections: a New Zealand case study, 2024.

hazard, another study²⁴ explored the link between extreme, damaging precipitation events and atmospheric rivers (ARs). The paper found a strong association between the two, with nine of the ten most damaging floods in Aotearoa New Zealand between 1980 and 2018 occurred during AR events.

In combination, these findings have implications for decision-makers as they plan for a warmer world, and prove the worth of a climate change research programme that focuses on extreme weather as opposed to averages so that a wider range of relevant climate change insights can be identified and fed into decisions about how excess water is managed.

3. Fire

Whakahura research identified that fire risk is increasing faster than most people realise.

In spite of an increase in uncontrolled fires since 2010, very little Aotearoa New Zealand-based research into the link between wildfires and climate change had been undertaken previously. Whakahura fire risk projections draw on more detailed spatial information than has been used in this country before, which improves resolution and accuracy, especially in areas far from observation stations. A key study²⁵ found that on average, weather conditions ideal for wildfires will increase in length and in terms of fire intensity potential, with the most severe wildfire danger being in the central-south inland areas of the South Island. The authors have provided maps which can aid planners and policy makers in prioritising adaptive infrastructure planning, for example, identifying powerlines in high-risk locations and tagging them for transition underground.

24 Article: Extreme Rainfall in New Zealand and its Association with Atmospheric Rivers, 2021.
25 Article: Aotearoa New Zealand's 21st-Century Wildfire Climate, 2022.



4. Identifying Real-World Impacts

KEY POINTS

- 1. The impacts of anthropogenic extreme weather are many and varied, including direct and indirect, economic, infrastructural, experiential and cultural.
- 2. Costs resulting from EWEs are already high and rising.
- 3. Māori are disproportionately affected by EWEs, yet emergency response and Disaster Risk Reduction efforts generally fail to involve iwi/hapū.
- 4. We are not well-prepared for the extreme weather we are already experiencing, and there is a risk this shortfall will increase into the future if adaptation activities are insufficient.
- 5. A collaborative approach to data collection and access is vital for future adaptation planning.

INTERDISCIPLINARY APPROACH

There are complex challenges inherent in responding to climate change, including scientific, economic, legal, social, cultural, engineering and environmental aspects. There is a growing awareness that solutions can only be developed through interdisciplinary collaboration. In the Whakahura Programme, physical scientists and economists have worked together: the former applying science to estimate the changing probability and intensity of extreme weather; the latter calculating what that implies for economic and social damages:

*"We need that sort of translation into dollars and cents and things that ultimately policy makers and the public are interested in."*²⁶

26 Ilan Noy

It is, however, not a straightforward relationship, and so the methods that economists have developed in their field are helpful in teasing out the implications of a changing climate. For example, how can we best: explore causality, analyse cost benefit choices, assess resource allocation, and deal with complexity?

Efforts to weave together climate science and mātauranga Māori have also been beneficial in terms of exploring culturally relevant impacts and costs of extreme weather. Through Whakahura research, those working on climate change adaptation are presented with a new set of considerations that can improve their work, whether they are updating infrastructure, strengthening social connectedness or improving hazard awareness within communities. Importantly, *"adaptation efforts must be inclusive of a variety of stakeholder viewpoints, especially Indigenous cultural values that may differ from Pakehā views of flood risk management."*²⁷

27 Article: The role of climate change in extreme rainfall associated with Cyclone Gabrielle over Aotearoa New Zealand's East Coast, 2023.



Identifying Real-World Impacts

Economic and human effects from extreme weather events, now and into the future

The most substantial cost of climate change is from the changing probability and intensity of extreme weather events. This cost is already very large and it is not distributed equally.



CONSIDERATIONS IN ESTIMATING COSTS

While extreme event attribution (EEA) science has been developing for the past two decades, it has only been brought to the task of calculating the socio-economic impacts²⁸ of extreme weather more recently; this approach is called extreme event impacts attribution (EEIA). There are still a number of methodological challenges and scientific disagreements to be resolved, and future improvements in available data and models will assist here.²⁹

It has been common for research in this area of inquiry to focus on direct costs, however, by capturing myriad indirect costs that inevitably result from these hazards, Whakahura researchers have helped pioneer the field of economic analysis of anthropogenic extreme weather costs.

28 There has so far been little work looking at environmental or ecological extreme weather impacts.
29 Article: Extreme events impact attribution: A state of the art, 2024.

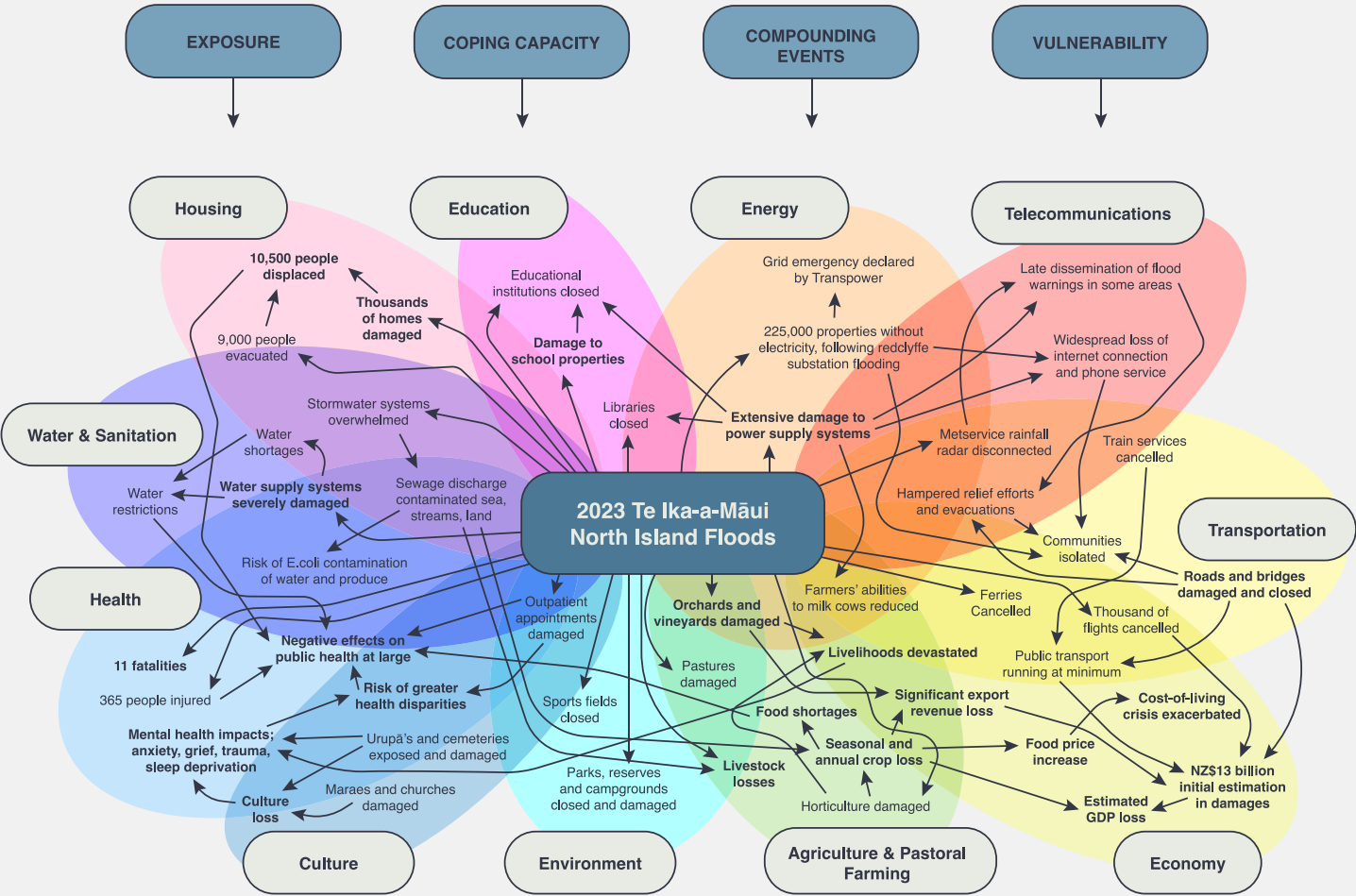


Fig 3: Impacts pathways among sectors affected by the 2023 Te Ika-a-Māui floods. (Long-term impacts are emphasised in bold)

As Fig 3 shows, impacts of the 2023 floods in Aotearoa New Zealand were wide-ranging, both direct and indirect, and they affected organisations, whanau and individuals, the environment, infrastructure and the wider economy.³⁰ Despite warnings given during Cyclone Gabrielle’s approach, significant negative impacts were still experienced. The research showed that because Māori are more likely to live with socioeconomic deprivation than other ethnicities, they experienced more significant negative impacts than non-Māori.

Another paper³¹ highlighted a number of potential areas of impact that are important to Māori but not usually considered by mainstream disaster risk reduction assessments and practices (physical, social, economic and environmental). These relate to mana and mauri and the interconnectedness of things, and can include, for example, taonga species (culturally significant flora and fauna), mahinga kai (traditional food sources and harvesting) and wāhi tapu (sacred sites).

30 Article: The role of climate change in extreme rainfall associated with Cyclone Gabrielle over Aotearoa New Zealand’s East Coast, 2023.
31 Article: A ‘te ao Māori’ disaster risk reduction framework, 2024.

FINANCIAL/INFRASTRUCTURAL IMPACTS

In their 2023³² paper looking at global costs of climate change, Newman and Noy explored the potential for applying attribution-based methods to estimating the global cost of extreme weather influenced by anthropogenic climate change. It drew on previous Whakahura research,³³ which aimed to develop a ‘bottom up’ method for quantifying approximate costs associated with extreme weather-related climate change. That study looked at droughts and floods in New Zealand during the ten years to 2017, and estimated that the portion of major-flood insurance costs attributable to anthropogenic influence on the climate was around \$140m.

The ambitious new research noted some limitations within the field of extreme event attribution, such as the skewed geographical coverage of attribution studies and the uneven attention paid to different hazard types in the literature, for example, greater coverage of heatwaves, while storms are under-studied. The researchers calculated an average annual cost of between US\$143b and US\$167b over the 2000-2019 period (accounting for both loss of life and economic damages) using FAR,³⁴ and when compared with findings from other research, this figure suggests that more commonly referenced, ‘top down’ estimates of climate change costs (using Integrated Assessment Models) may constitute underestimates.

HUMAN AND CULTURAL IMPACTS

The Whakahura Programme produced several papers exploring costs associated with Hurricane Harvey. One paper³⁵ brought together researchers from four disciplines: climate scientists, flood hydrologists, an economist and a sociologist. The research, which focused on flooding in Harris County, Texas, resulting from the 2017 hurricane, showed that climate change was responsible for between 37% and 58% of the total costs, and that between 30% and 50% of flooded properties would not have flooded without climate change. Further, it found that, in this instance, more vulnerable communities experienced inequitable effects, and there is the suggestion that climate change-induced extreme weather may potentially exacerbate existing social inequalities. These findings have implications for town planning, climate-related legal cases, recovery funding

32 Article: The global costs of extreme weather that are attributable to climate change, 2023.
33 Article: Climate change attribution and the economic costs of extreme weather events: a study on damages from extreme rainfall and drought, 2020.
34 Fraction of Attributable Risk.
35 Article: Social inequalities in climate change-attributed impacts of Hurricane Harvey, 2022.

and insurance, and show that adaptation work now and into the future should emphasise the importance of reducing social inequalities.

Extending on this theme, Whakahura research has shown that Cyclone Gabrielle had a particularly devastating impact on Māori communities in large part due to existing socioeconomic challenges. Despite this, emergency management activities have not adequately addressed the specific needs of hapū and iwi in the cyclone’s aftermath.³⁶ This research underscores the urgent need for better integration of Māori expertise with emergency response planning and decision-making to ensure that the unique needs of Māori communities are effectively addressed in relation to future extreme weather events.

THE DISASTER LOSS DATABASE

At the current time, Aotearoa New Zealand does not have a national information repository for collating the costs of disasters in general, or climate change and extreme weather-related damages more specifically. This is a longstanding knowledge gap that puts this country out of step with many others.

The Whakahura Programme had aimed to remedy this through establishing a Disaster Loss Database (DLDB) that would constitute a publicly available, evidentiary foundation for the costs, damages and vulnerabilities associated with anthropogenic extreme weather.

Currently, the only easily accessible data that could feed into this type of resource comes from the insurance industry; relevant information from entities such as government departments is not collected, collated or made publically available. In effect this means that the impacts from extreme weather on infrastructure such as roads, bridges, sewerage systems, the power grid and public buildings etc, are not being quantified, and nor are the health or indirect impacts on people. As a result, decision-makers are operating without being fully informed by evidence:

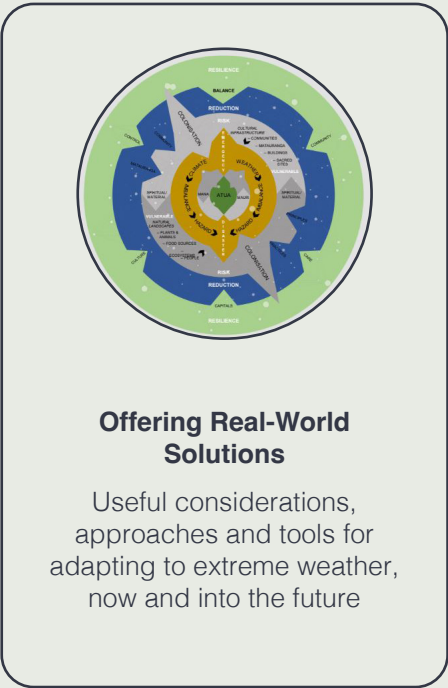
“Irrespective of climate change, if we want to manage flood risk and storm risk and drought risk and heat wave risks in New Zealand, then we need to know what we’re dealing with. At this point, all the policy around flood risk or storm risk and so on is being done in the dark because we don’t know the extent of the problem.”³⁷

36 Article: A ‘te ao Māori’ disaster risk reduction framework, 2024.
37 Ilan Noy



5. Offering Real-World Solutions

1. Knowledge transfer between researchers and decision-makers can be enhanced by relationships and end-users appreciating the importance of climate change.
2. Knowledge transfer between researchers and decision-makers can be hindered by institutional contexts, a failure to recognise Māori input into adaptation, and maintenance of the status quo.
3. The Whakahura Programme produced a number of solution-based outputs, including:
 1. Changing the National Narrative
 2. Supporting the Reserve Bank’s Stress Tests
 3. The Te Ao Māori DRR Framework
 4. The Metservice Heat Alert
 5. The Rokohouia Delta Case Study
 6. The Loss of Design Life of Infrastructure Tool



Decision-makers and policy and planning professionals need access to robust, forward-looking evidence that supports adaptation. Even with the best evidence-based advice, however, “*change is hard and being responsive to alternative ways of thinking is difficult, so you really need clear direction, clear rules, and policies in place in order to provide people with guidance.*”³⁸ An active interface between researchers and research users is potentially influential in terms of knowledge transfer than can underpin real-world solutions.

So, how have Whakahura researchers experienced the role of influencing future adaptation strategy and action in Aotearoa New Zealand?

38 Shaun Awatere

THE RESEARCH-POLICY INTERFACE

The interface between researchers/scientists and decision-makers is complex, involving multiple factors, such as competing priorities, prior knowledge and experiences, and emotion. As a result, physical scientists do not have a direct line into decision-making. Yet there are instances where the Whakahura Programme has supported economic decision-making and human wellbeing, and other examples where there is clear potential to do so in the future.

In the first instance, the programme concentrated on a fairly small number of decision makers, for example, the **New Zealand Treasury** and the **Reserve Bank of New Zealand**. While there was an overall focus at the national, rather than local or regional level, specific projects also collaborated with two iwi: **Ngāti Porou** and **Ngāi Tahu**.

Other sub-national organisations, such as local and regional councils, are well aware they need to address climate change, and the outputs from Whakahura will be of use to them, for example, through informing managed retreat strategies.

In one example of a direct input into policy, Whakahura provided evidence for The Ministerial Inquiry into land use causing woody debris and sediment-related damage in Te Tairāwhiti-Gisborne and Wairoa. This has subsequently fed into recommendations for district councils regarding land use planning rules and methods for creating diverse landscapes.



There are specific factors that appear to have helped or hindered knowledge transfer at the interface, some of which are commented on below.

Some factors that help knowledge transfer:

Relationships

“*I think the reflexive approach of sitting down with people and trying to understand what they’re really interested in and then trying to shine new light on that is what we wanted to do.*”³⁹

The Whakahura team aimed to have a small number of deeper, more connected relationships as opposed to a greater number of passing associations. Personal acquaintances have been instrumental in transmitting knowledge, as has dedicated project management, particularly when connections were purposefully maintained: building the relationship, being persistent, and checking in. In this way, it was possible to gain a strong understanding of what stakeholders wanted and then contribute information at the right times:

“*By maintaining a high-touch relationship with selected stakeholders, we could offer decision-ready advice when needed, and were able to have a significant influence on key policies.*”⁴⁰

Relationships with iwi were possible via team members with pre-existing relationships, such as Shaun Awatere, Tui Warmenhoven and John Reid. These connections facilitated, for example, an interactive briefing on key research findings with Ngāti Porou and Ngāi Tahu.

Organisational appreciation of the importance of climate change

Conversations with the Reserve Bank were very useful because they fed into the organisation’s stress testing⁴¹ practices, which assess how resilient banks and insurers would be in the face of certain risks.

It has meant that when the banks approach macroeconomic risk, they are able to factor in climate trends when considering seasonal forecasting, for example.

“*I think the qualitative conversations were really useful in focusing minds on possible macroeconomic risks associated with extreme weather.*”⁴²

The Aotearoa New Zealand research environment experiences a number of disadvantages such as remoteness, and funding feast or famine compared with other countries, however, this is also one of the few places in the world where climate scientists have the opportunity for direct access to the central bank.

39 Dave Frame
40 Belinda Store
41 The 2023 Climate Stress Test results are available [here](#).
42 Dave Frame



Some factors that hinder knowledge transfer:

Myriad institutional contexts and internal politics

It can be difficult for outsiders to grasp changing institutional contexts. For example, planning cycles may mean that the civil service is only receptive to outside input during short windows of time, and regular changes of staff and the associated periodic erasure of institutional memory can make relationship-building difficult. Additionally, members of the team found that government departments were often reluctant to share data that would support evidence-based adaptation planning.

Failure of decision-making institutions to recognise Māori in adaptation planning and practice

The extent to which organisations are willing and able to engage with iwi and hapū in developing climate change adaptation strategies is mixed, and this is despite the Crown’s obligations under te Tiriti o Waitangi to address the unique effects of climate change on Māori rights and interests. In effect, this means that even when useful tools and plans are developed with a te ao Māori lens and are subsequently made available to public agencies, receptive leadership is required to then implement those resources.

Maintenance of the status quo and lack of impetus to focus on climate change adaptation collectively

Some of these factors have already been discussed, such as the emphasis placed on slower moving effects of climate change, (e.g.seal level rise) and Aotearoa New Zealand’s historically low level of concern with heat. However, additional systemic factors are also at play.

In terms of whole-of-government functions, different types of extreme weather are in practice considered the concern of single government departments. For example, drought is considered to be an issue for farm production and so is under the purview of the Ministry of Primary Industries, however, this hazard also results in impacts beyond agriculture, which in fact cross over into other domains such as health and local government. Ideally there would be more collaboration across public entities (including research funders) so that necessary extreme weather research can be undertaken with strong connections amongst a range of decision-makers.

“*Heat research, for example, just falls through the cracks because no one takes ownership for it.*”⁴³

43 Luke Harrington



SOLUTION-BASED OUTPUTS

In addition to researchers seeking to better understand real-world changes and identify real-world impacts, the programme has also created outputs that are useful, useable and used by decision-makers, particularly in the policy and planning arenas. The term ‘decision-ready research’ was used during interviews undertaken with research leaders in preparation of this paper, and reflects a desire to provide information tailored to users’ needs where possible.

Six examples are provided below:

1. Changing the National Narrative

“Decision-making at every level from homeowners to the Prime Minister now considers the changing intensity and likelihood of extreme weather events much more than they did five years ago.”⁴⁴

Recent extreme weather events have underscored the findings of the Whakahura Programme, in particular, their increasing likelihood and intensity. The Auckland Anniversary floods, and Cyclone Gabrielle were around 20 times more damaging than any other event during the past three decades, and around 10 times more costly than the most expensive event on record, and yet they happened just two weeks apart in 2023. These events have likely helped to change people’s perceptions of the significance of extreme weather.

Whakahura researchers’ work has contributed to organisations, communities and individuals becoming more

44 Ilan Noy

aware of extreme weather and its impacts. This applies to the field of insurance, for example, where economists working in the Whakahura Programme have been communicating the link between anthropogenic climate change and insurability for a decade. There was a time when some private insurers were dismissive of significant future vulnerabilities, but now not only does the entire industry understand the challenges, but ordinary people are arguably more likely to consider extreme weather potential when buying a home:

“Now, I think everyone understands that it is happening - not going to happen - it’s happening.”⁴⁵

For the Vision Mātauranga team, a key focus has been socialising the kaupapa of climate change with Māori communities, and equally, helping decision-makers realise the need for, and benefits of, Māori being integrally involved in the climate change adaptation conversation. Promoting the notion of a connected environment and the foundational role of land use decisions are vital elements of effective adaptation:

“Because the economic system is set up in a way that we are very monoculturally focused, when you have these external shocks to the system, there are huge impacts on the community. And so we’re trying to change up that narrative through a whakaaro Māori lens around looking at creating greater relationality between people and the taiao, people and the environment, so it does become part and parcel of the thinking when it comes to decisions around what to do for the future.”⁴⁶

45 Ilan Noy
46 Shaun Awatere

2. Supporting the Reserve Bank’s Stress Testing Work

What is it? When the Reserve Bank decided to integrate climate change considerations into its stress testing⁴⁷ regime in 2021, members of the Whakahura research team advised on the best methodological approach. This contribution was based on a synthesis of Whakahura-funded research and was enabled by quarterly meetings.

Why is it useful? Testing and improving the capability of this country’s financial institutions to manage climate-related risks is an important component of financial stability. Extreme weather events are already having a significant impact on the economy, and constitute exactly the type of shock the Reserve Bank is interested in understanding:

“This work helped ensure that commercial banks in New Zealand started to quantify the physical risk of climate change, and it also encouraged those banks to lift their internal capability on climate change.”⁴⁸

3. Te Ao Māori Disaster Risk Reduction (DRR) Framework

What is it? The Framework⁴⁹ provides guidance on points of connection and overlap between standard DRR concepts and a te ao Māori (Māori world view) DRR approach. It serves as a practical tool for emergency management officials, who draw primarily from technocratic approaches, to begin considering local Māori perspectives, so that in the face of an extreme weather event, they can more easily identify when iwi/hapū input is most needed. The framework is supported by a detailed discussion of Māori DRR thinking.

Why is it useful? Mainstream risk assessment processes typically prioritise roading infrastructure, the power grid and homes, for example, however, the wider interests of whanau and hapū, such as impacts on the connected ecosystem, are generally overlooked. These considerations include, for example, “Taonga species in a particular area, or places that we have a lot of social and emotional connection to: wāhi tapu - historical areas, marae - where we have community gatherings, as well as urupā - where the bones of our tipuna are held.”⁵⁰ Māori have approaches to managing risk in an environment that validly sit alongside mainstream DRR planning and procedures, and which offer very practical adaptation solutions - this Framework offers a way forward for ensuring Māori are involved in extreme weather hazard management decisions.

4. Metservice Heat Alert

What is it? This new resource was initiated from within the Whakahura Programme when researcher Luke Harrington approached MetService about creating a heat-related service. The original concept has been developed over the past three years and provides daily heat-related health warnings during summer for vulnerable populations.

47 Stress testing assesses the level of resilience banks and insurers have in the face of severe but plausible risks. Results inform the Reserve Bank’s work in: understanding of financial stability, policy-making, and supporting institutions to manage their own risk, including setting financial safety buffers.
48 Belinda Storey
49 Article: A ‘te ao Māori’ disaster reduction framework, 2024.
50 Shaun Awatere

Why is it useful? It has highlighted the increasing likelihood of extreme heat in this country and provides an early example of how public institutions can be more proactive about managing heat-related risks.

5. Leading by Example: Ngāi Tūāhuriri and the Rokohouia Delta Case Study

What happened? As a way of demonstrating the benefit of applying mātauranga Māori to current climate change challenges, a case study was built around a collaboration between Ngāi Tūāhuriri (a hapū of Ngāi Tahu) and neighbouring hapū, who together have developed a Wellbeing Index that flows into ecosystem management for the Rokohouia Delta in Canterbury. Grounded in the deep ties between hapū and the delta, this partnership achieved both cultural revitalisation (through regeneration of mahinga kai) and climate change adaptation.

Why is it useful? It demonstrates that the impacts of extreme precipitation (and increasing water extraction) can be reduced when hapori Māori⁵¹ apply their longstanding knowledge of a local area and have the resources to plan and apply location-appropriate, holistic, nature-based solutions along a whole catchment. It also underscores the value of civil institutions and Māori entering into genuine partnership on climate change:

“We saw that flood events could be attenuated or decreased by as much as 30% to 50% through clever nature-based solutions and undertaking ecosystem reconstruction throughout a catchment.”⁵²

6. A Tool for Calculating the Loss of Design Life in Infrastructure under Climate Change - Proof of Concept

What is it? This tool offers an innovative atmospheric-hydrological modelling chain to assess how the Annual Exceedance Probability of extreme precipitation events will evolve as global temperatures increase. Currently at the proof-of-concept stage, this work introduces a novel methodology to estimate the time until design failure of infrastructure under climate change, termed ‘Loss of Design Life’.

Why is it useful? This process provides a mechanism for quantifying the financial implications of climate change on critical infrastructure investments, thereby informing economic considerations of adapting today’s infrastructure for future climate scenarios:

“This new methodology creates a mechanism to directly translate physical science outputs into financial decision-making inputs.”⁵³

51 Māori communities.
52 John Reid, [Climate Change Adaptation and Māori: Policy, Impact, and Solutions Webinar](#), 10 September 2024.
53 Belinda Storey.

6. What Comes Next?

The Whakahura Programme was heavily climate-science-focused and dedicated to advancing the understanding and modelling of extreme weather events within the context of a changing climate. There is still a need for further work in this area, for example, studying the relationship between atmospheric rivers and extreme precipitation or how different types of extreme weather interact to amplify or offset risk.

“Whakahura laid the groundwork for understanding how extreme weather is affecting us now and how it’s emerging in the near future. The research has highlighted this as something we need to worry about, but now we need to actually go into trying to address how we can use that understanding to make the decisions we need to make.”⁵⁴

In order to fully leverage the value of Whakahura’s outputs, future research should expand across multiple domains to produce socio-economic, cultural and impact-focused assessments

This should include studying financial climate-related risks, seeking more detailed understanding of economic impacts and adaptation policies across locations and sectors, and exploring how social vulnerabilities exacerbate the effects of anthropogenically influenced extreme weather. Such a focus would ensure a more comprehensive understanding of how extreme events affect iwi and hapū, communities, regions and government functions, and thus help to maximise the benefit of future investments in climate adaptation and risk reduction.

Researching regional/localised extreme weather and adaptation approaches, including implications for land use, is of particular relevance to Māori. Inherent within this is a consideration of scale, for example, application of climate models at the individual catchment level, and joining weather data and ecosystem data in ways that can inform community adaptation practices.

Further exploration of how climate change may alter Aotearoa New Zealand’s place within the global community is another interesting avenue of inquiry, for example, what will the increasing incidence and intensity of extreme weather mean for international trade?

Finally, greater consideration of how to facilitate the interface between science/researchers and policy/decision-makers, would be beneficial. For example, how can data generated in this country, particularly that held by government agencies, be applied to guiding adaptation strategies and investment? How can system-level protocols for collection, storage, curation and access to such data be improved? How can cross-agency collaboration be incentivised in this area?

⁵⁴ Dáithí Stone.



7. Programme Summary

The Whakahura Programme aimed to enhance understanding of anthropogenically influenced extreme weather and its impacts in order to improve economic decision-making and human wellbeing now and into the future. It has produced a robust body of evidence that can be applied to adaptation efforts both nationally and internationally.

The programme’s outputs can be categorised into three areas: understanding real-world changes, identifying real-world impacts and offering real-world solutions. In addition, the researchers have advanced the thinking around data and methodological approaches for this field of inquiry.

In Aotearoa New Zealand, climate science, and narratives around climate change, have tended to focus on slower moving aspects such as sea level rise or average temperature increases. However, when we look more closely, we can see that extreme weather events present a far greater immediate risk.

In terms of **understanding real-world change**, Whakahura research has shown that EWEs are increasing in frequency and intensity. Some hazards are changing more quickly than others in this country, namely, extreme heat, short intense rainfall events, and fire risk. Further, those locations already vulnerable to particular EWEs will tend to experience more of those events into the future.

Methodologically, quantifying change in the likelihood or intensity of EWEs resulting from anthropogenic climate change is complex and can be approached in different ways. This continues to be an active area of research, and Whakahura researchers are significant contributors to the global research frontier. In Whakahura, researchers explored the efficacy of ‘bottom up’ approaches in comparison to more commonly used ‘top down’ macro estimates, and found that careful consideration is needed in terms of the research questions posed, data sets used, and models and techniques applied. As highlighted in one of our high profile papers, no single method works best in all situations.⁵⁵

When we bring social science alongside physical science to better **identify real-world impacts**, it becomes clear that extreme weather events are causing myriad negative effects, which can take economic, infrastructural, cultural and experiential forms, and may be direct or indirect.

Working collaboratively, physical scientists and economists have taken insights about extreme event attribution (EEA) methodology and applied these to further exploring the applicability of extreme event impact attribution (EEIA); they have shown that ‘top down’ approaches may in fact be producing underestimates of the anthropogenic components of extreme weather costs. This has implications for adaptation funding, future infrastructure investment decisions, and climate-related litigation, among other things.

⁵⁵ Article: On the attribution of the impacts of extreme weather events to anthropogenic climate change, 2022.

Ultimately, the research has shown that costs resulting from extreme weather are already high and are rising. These costs have been shown to be unevenly distributed, with extreme weather having the potential to cause more negative impacts for those in lower socioeconomic circumstances. This holds true within Aotearoa New Zealand where Māori are disproportionately affected, and yet emergency management and adaptation planning has largely failed to involve iwi and hapū meaningfully.

In terms of **offering real-world solutions**, this work has already enhanced resilience planning, informed policy, and improved preparedness for extreme weather events in Aotearoa New Zealand. In addition to generally contributing to a more informed national narrative, the programme has also delivered: guidance to the Reserve Bank’s Stress Tests; the Te Ao Māori DRR Framework; the MetService Heat Alert; the Rokohouia Delta Case Study; and a proof-of-concept tool for calculating the Loss of Design Life of Infrastructure.

Of specific relevance to Aotearoa New Zealand, the research has demonstrated that Māori have approaches to managing risk that validly sit alongside mainstream DRR planning and procedures, and which offer very practical adaptation solutions. When hapori Māori apply their longstanding knowledge of a local area and have the resources to plan and apply location-appropriate, holistic, nature-based solutions along a whole catchment, climate adaptation can be more effective, with benefits anticipated to be realised by the wider community and future generations.

Through their experiences in Whakahura, the team have identified some potential systemic changes that could strengthen the **interface between researchers and decision-makers**, thereby releasing the full benefit of climate research, particularly when it comes to extreme weather. These relate to taking a joined up approach to data management, strengthening partnerships between public organisations and iwi/hapū, and improving collaboration and rethinking scale within government functions connected with climate change.

In terms of **future extreme weather research**, it is suggested here that although there is still more science-based exploration needed, for example, in the area of extreme heat, fully leveraging the value of Whakahura outputs also relies on expanding into socio-economic and cultural domains, and impact-focused assessments. Economic analysis of extreme events is key to incorporating physical climate science into the adaptation policies we need to meet the growing challenge of extreme weather challenges in a warmer world.

APPENDIX 1: LIST OF RESEARCHERS

Name	Role	Organisation
Dave Frame	Professor, Physical and Chemical Sciences / Atmospheric Physics	University of Canterbury
Ilan Noy	Chair in the Economics of Disasters and Climate Change, Economics and Finance	Victoria University of Wellington
Dáithí Stone	Climate Scientist, Atmospheric Physics	NIWA
Shaun Awatere	Kaihautū Māori Research Impact Leader, Economics	Manaaki Whenua
Greg Bodeker	Owner and Director, Atmospheric and Climate Science	Bodeker Scientific
Belinda Storey	Managing Director, Economics	Climate Sigma
Nienke Kloppenburg	Project Manager	Climate Sigma
Leroy Bird	Data Scientist, Data Science	Bodeker Scientific, RedSkyAI
Elodie Blanc	Research Fellow, Economics	Motu
Emily Campbell	Community Planner, Land Use and Urban Planning	Beringia Community Planner
Trevor Carey-Smith	Climate Scientist	NIWA
Sam Dean	Principal Scientist - Climate, Atmospheric Physics	NIWA
Bapon Fakhruddin	Senior DRR and Climate Resilience Specialist	Tonkin & Taylor (Green Climate Fund)
Peter Gibson	Climate Scientist	NIWA
Luke Harrington	Senior Lecturer, Environmental Science	University of Waikato
Annie Huang	Research Assistant, Ngāi Tahu Research Centre	University of Canterbury
Stefanie Kremser	Scientist, Meteorology	Bodeker Scientific
Erena Le Heron	Social Scientist, Geography	Le Heron Leigh Consulting
Gregor Macara	Climate Scientist	NIWA
Adrian McDonald	Professor, Associate Head, Physical and Chemical Sciences	University of Canterbury
Nathanael Melia	Founding Director, Climate Science	Climate Prescience
Chris Noble	Chief Meteorologist, Atmospheric Physics	MetService
Sally Owen	Researcher, Economics	Victoria University of Wellington
Mihiata Pirini	Researcher, public & administrative law, Treaty of Waitangi, tikanga and state law	University of Otago
Pia Pohatu	Researcher, Iwi and Hapū environmental planning	Hikurangi Enterprises
Sapna Rana	Scientist	MetService, ASB Bank
John Reid	Senior Research Fellow, Ngāi Tahu Research Centre	University of Canterbury
James Renwick	Professor of Physical Geography, Geography, Environment and Earth Sciences	Victoria University of Wellington
Laura Revell	Associate Professor, Physical and Chemical Sciences	University of Canterbury
Suzanne Rosier	Climate Scientist, Atmospheric Physics	NIWA
Matt Rout	Senior Research Fellow, Ngāi Tahu Research Centre	University of Canterbury
Sharlan Shields	Research Assistant, Economics	Victoria University of Wellington, DOC
Abha Sood	Climate Scientist	NIWA, climate@aranyani
Laura Tilley	Disaster Risk and Resilience Specialist, Disaster Risk	Tonkin & Taylor, University of Canterbury
Jordis Tradowsky	Atmospheric Scientist / International Advisor, Atmospheric Physics	Bodeker Scientific, MET Norway
Tom Uher	Research Assistant, Economics	Victoria University of Wellington
Tui Warmenhoven	Researcher, government, educational and tribal organisations	He Oranga mo Nga Uri Tuku Iho Trust
Christian Zammit	Hydrologist, Hydrology	NIWA

Students included: Arlo Heynes (PhD), Hunter Douglas (PhD), Apurba Roy (PhD), Cameron McElrich (PhD), Gokul Vishwanathan (PhD), Miloud Lacheheb (PhD), Laura Queen (PhD), Fergus Robertson (Master), Emily Campbell (Master), Rebecca Newman (Master), Lucas Larraman (Master), Noel Del Castillo (PhD), Mui Nguyen (PhD), Quanfu Zhang (PhD), and Tom Mars (Master).

APPENDIX 2: LIST OF PUBLICATIONS (PUBLISHED)

Title	Report Year	Authors (Whakahura)
Processes and principles for producing credible climate change attribution messages: lessons from Australia and New Zealand	2024	Luke Harrington, Suzanne Rosier, Stone, Dave Frame
Anthropogenic influence on precipitation over Aotearoa New Zealand for differing circulation types	2024	Adrian McDonald, Greg Bodeker, Suzanne Rosier, James Renwick
High-resolution CCAM model simulations over New Zealand for the detection and attribution of climate extremes	2024	Peter Gibson, Dáithí Stone, Sam Dean, Suzanne Rosier, Abha Sood
Conference Paper: Future changes in dry and wet extremes hidden within annual rainfall signals: a New Zealand case study. XXVIII General Assembly of the International Union of Geodesy and Geophysics (IUGG) (Berlin 2023).	2024	Suzanne Rosier, Luke Harrington
Sensitivity of extreme precipitation to climate change inferred using artificial intelligence shows high spatial variability	2024	Greg Bodeker, Leroy Bird
An assessment of extra-tropical cyclone precipitation extremes over the Southern Hemisphere using ERA5		Adrian McDonald, Cameron McElrich, James Renwick
An assessment of Southern Hemisphere extra-tropical cyclones in ERA5 using WindSat	2024	Cameron McElrich, James Renwick, Adrian McDonald
Regional characteristics of extreme precipitation events over Aotearoa New Zealand	2024	Adrian McDonald, Gokul Vishwanathan, Chris Noble, Dáithí Stone, Suzanne Rosier, Greg Bodeker
Event attribution is ready to inform loss and damage negotiations	2024	Ilan Noy, Dáithí Stone, Suzanne Rosier, Dave Frame, Rebecca Newman
A ‘te ao Māori’ disaster risk reduction framework	2024	Matt Rout, Shaun Awatere, John Reid, Tui Warmenhoven
Climate change emergence over people's lifetimes	2024	Hunter Douglas, Luke Harrington
Extreme events impact attribution: a state of the art	2024	Ilan Noy, Dáithí Stone
Damages and costs of forest wildfires in New Zealand using satellite data	2024	Ilan Noy, Elodie Blanc
Nowcasting from space: tropical cyclones' impacts on Fiji's agriculture	2024	Elodie Blanc, Ilan Noy
2022 early-summer heatwave in Southern South America: 60 times more likely due to climate change	2024	Luke Harrington, Friederike Otto
Robust changes to the wettest and driest days of the year are hidden within annual rainfall projections: a New Zealand case study	2024	Luke Harrington, Dave Frame, Suzanne Rosier
Emergence of multivariate climate change signals	2024	Luke Harrington
Adapting to climate change through nature-based solutions and indigenous knowledge: the case for landscape-scale ecosystem regeneration in the Rokohouia Delta	2024	Shaun Awatere, John Reid
Signal-to-noise calculations of emergence and de-emergence of stratospheric ozone depletion	2024	Laura Revell, Hunter Douglas, Dave Frame
Economists are not engaged enough with the IPCC	2024	Ilan Noy
Climate change adaptation through an integrative lens in Aotearoa New Zealand	2024	Shaun Awatere, Christian Zammit, Sam Dean
Extended ozone depletion and reduced snow and ice cover—Consequences for Antarctic biota	2024	Laura Revell
Continuing benefits of the Montreal Protocol and protection of the stratospheric ozone layer for human health and the environment	2024	Laura Revell
Plastics in the environment in the context of UV radiation, climate change and the Montreal Protocol: UNEP Environmental Effects Assessment Panel. Update 2023	2024	Laura Revell
Environmental plastics in the context of UV radiation, climate change, and the Montreal Protocol	2024	Laura Revell
The impact of ocean warming on selected commercial fisheries in New Zealand	2024	Ilan Noy
Cyclone Gabrielle as a design storm for northeastern Aotearoa New Zealand under anthropogenic warming	2024	Dáithí Stone, Greg Bodeker, Sam Dean, Luke Harrington, Suzanne Rosier
The Costs of Inaction: Calculating loss and damage from extreme weather events in Small Island Developing States	2024	Ilan Noy
Impact of extratropical cyclones, floods, and wildfires on firms' financial performance in New Zealand.	2023	Ilan Noy, Apurba Roy
Income and floods in New Zealand	2023	Apurba Roy
Event attribution is not ready for a major role in loss and damage	2023	Luke Harrington
Climate change increased extreme monsoon rainfall, flooding highly vulnerable communities in Pakistan	2023	Luke Harrington, Friederike Otto

Title	Report Year	Authors (Whakahura)
Causality and the fate of climate litigation: the role of the social superstructure narrative	2023	Luke Harrington, Friederike Otto
The global costs of extreme weather that are attributable to climate change	2023	Rebecca Newman, Ilan Noy
Storyline attribution of record-shattering spatially compounding flood-heat event	2023	Dáithí Stone
Deep learning for stochastic precipitation generation - deep SPG v1.0	2023	Greg Bodeker, Leroy Bird, Suzanne Rosier
Impacts of droughts and floods on agricultural productivity in New Zealand as measured from space	2023	Elodie Blanc, Ilan Noy
Extreme heat in New Zealand: a synthesis	2023	Luke Harrington, Dave Frame
Socialising attribution of climate events: Progress, myths and future outlook	2023	Luke Harrington
Social Inequalities in Climate Change-Attributed Impacts of Hurricane Harvey	2023	Ilan Noy, Dave Frame
Changes to population-based emergence of climate change from CMIP5 to CMIP6	2023	Luke Harrington, Dave Frame, Laura Revell, Hunter Douglas
Scientific report New Zealand Floods - The role of climate change in extreme rainfall associated with Cyclone Gabrielle over Aotearoa New Zealand's East Coast	2023	Luke Harrington, Sam Dean, Shaun Awatere, Suzanne Rosier, Laura Queen, Peter Gibson, Dáithí Stone, Dave Frame, Friederike Otto
Positive correlation between wet-day frequency and intensity linked to universal precipitation drivers	2023	Adrian McDonald, Cameron McElrich, Gokul Vishwanathan, James Renwick, Sapna Rana
Mean and extreme precipitation over Aotearoa New Zealand: A comparison across multiple different estimation techniques	2023	Gokul Vishwanathan, Adrian McDonald, Dáithí Stone, Suzanne Rosier, Sapna Rana, Chris Noble
Underestimated climate risks from population ageing	2023	Luke Harrington, Friederike Otto
Limited role of climate change in extreme low rainfall associated with southern Madagascar food insecurity, 2019–21	2023	Luke Harrington
Catastrophic Droughts and Their Economic Consequences	2022	Ilan Noy
Spatiotemporal trends in near-natural New Zealand river flow	2022	Laura Queen
Aotearoa New Zealand's 21st Century Wildfire Climate	2022	Nathanael Melia, Sam Dean, Luke Harrington, Dave Frame
Temperature emergence at decision-relevant scales	2022	Luke Harrington
Integrating attribution with adaptation for unprecedented future heatwaves	2022	Luke Harrington, Dave Frame
Influence of Ozone Forcing on 21st Century Southern Hemisphere Surface Westerlies in CMIP6 Models	2022	Laura Revell, Hunter Douglas, Dave Frame
A Māori Approach to Environmental Economics: Te ao tūroa, te ao hurihuri, te ao mārama—The Old World, a Changing World, a World of Light. In Oxford Research Encyclopedia of Environmental Science.	2022	Matt Rout, Shaun Awatere, John Reid
Loss and damage from climate change: A new climate justice agenda	2022	Luke Harrington
Quantifying uncertainty in aggregated climate change risk assessments	2022	Luke Harrington, Friederike Otto
Transient and Quasi-Equilibrium Climate States at 1.5°C and 2°C Global Warming	2022	Luke Harrington, Dave Frame, Dáithí Stone
Progress and Challenges of Demand-Led Co-Produced Sub-Seasonal-to-Seasonal (S2S) Climate Forecasts in Nigeria	2022	Dáithí Stone
On the attribution of the impacts of extreme weather events to anthropogenic climate change	2022	Dáithí Stone, Suzanne Rosier, Dave Frame
The Life and Times of the Weather Risk Attribution Forecast	2022	Dáithí Stone
Nonlinear response of Asian summer monsoon precipitation to emission reductions in South and East Asia	2022	Dave Frame
Winter isn't what it used to be	2022	Dáithí Stone
The effect of experiment conditioning on estimates of human influence on extreme weather	2022	Dáithí Stone, Sue Rosier, Leroy Bird, Luke Harrington, Sapna Rana, Sam Dean
Income and extratropical cyclones in New Zealand	2022	Ilan Noy, Apurba Roy
Extreme weather impacts of climate change: an attribution perspective	2022	Luke Harrington, Friederike Otto
He huringa āhuarangi, he huringa ao: A changing climate, a changing world. Te Arotahi Series Paper, 7	2022	Shaun Awatere, John Reid

Title	Report Year	Authors (Whakahura)
Rethinking extreme heat in a cool climate: a New Zealand case study	2021	Luke Harrington
The question of Life, the Universe, and event attribution	2021	Dáithí Stone, Dave Frame, Suzanne Rosier
Implications of Warming on Western United States Landfalling Atmospheric Rivers and Their Flood Damages.	2021	Dáithí Stone
Diversification of forestry portfolios for climate change and market risk mitigation. Journal of Environmental Management, 289, 112482.	2021	Nathanael Melia
Extreme rainfall in New Zealand and its association with Atmospheric Rivers	2021	Suzanne Rosier, Luke Harrington
The economic costs of Hurricane Harvey attributable to climate change	2020	Ilan Noy, Suzanne Rosier, Dave Frame
Climate change attribution and the economic costs of extreme weather events	2020	Suzanne Rosier, Ilan Noy, Luke Harrington, Dáithí Stone, Sam Dean, Dave Frame
Observed Emergence of the Climate Change Signal: From the Familiar to the Unknown	2020	Dave Frame
Towards an inventory of the impacts of human-induced climate change	2020	Dave Frame, Luke Harrington, Friederike Otto
On the role of anthropogenic climate change in the emerging food crisis in southern Africa in the 2019–2020	2020	Dáithí Stone
A seven-fold rise in the probability of exceeding the observed hottest summer in India in a 2°C warmer world.	2020	Dáithí Stone
Who Cares? Future Sea Level Rise and House Prices	2020	Ilan Noy
Wellbeing after a managed retreat: Observations from a large New Zealand program	2020	Ilan Noy
Paying a Price of Climate Change: Who Pays for Managed Retreats	2020	Ilan Noy

APPENDIX 2: FORTHCOMING PUBLICATIONS

Publication	Authors
Loss of Design Life in Infrastructure Under Climate Change	Belinda Storey, Christian Zammit
Māori framework for climate change adaptation - Implementation and adaptation strategies	Shaun Awatere, Erena Le Heron, Emily Campbell, Tui Warmenhoven
Kia Whakakorowai i a Papatuānuku, Restoring the cloak of Papatuānuku: An Indigenous conceptualisation of extreme weather events	Shaun Awatere, Erena Le Heron, Emily Campbell, Tui Warmenhoven
Dangerous epicentres of heat stress during Ramadan are predictable	Luke Harrington
The recent climate in the context of a Paris Agreement 1.5°C world	Luke Harrington
Chapter two - in Meteorology of the Southern Hemisphere (American Meteorological Society monograph) - The stratosphere in the Southern Hemisphere	Laura Revell
Fingerprint of anthropogenic climate change detected in long-term western North American fire weather trends	Laura Queen, Sam Dean, Dáithí Stone, James Renwick, Nathanael Melia
The legal impacts of extreme weather events on iwi, hapū, and Māori	Mihiata Pirini
Attributing extreme heat-related mortality to climate change: an interdisciplinary case study of the 2009 Australian heatwave in the state of Victoria, Australia	Dáithí Stone
Drivers of regional variation in the de-emergence of climate change under negative emissions	Hunter Douglas
Detecting Rising Wildfire Risks for South East England	Nathanael Melia
Detection and attribution of climate change impacts on coupled natural-human systems in the Andes	Dáithí Stone